On demand: can demand response live up to expectations in managing electricity systems?

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On demand: Can demand response live up to expectations in managing electricity systems?

Highlights

- Residential consumer engagement in DR trials and programmes is systematically reviewed.
- There is a large evidence base but findings are complex and often inconsistent.
- Modelling studies tend to make optimistic assumptions about consumer engagement.
- The evidence is strongest for relatively simple and predictable forms of DR.
- More research and trial activity is needed on dynamic pricing and new loads.

Abstract

Residential demand response (meaning changes to electricity use at specific times) has been proposed as an important part of the low carbon energy system transition. Modelling studies suggest benefits may include deferral of distribution network reinforcement, reduced curtailment of wind generation, and avoided investment in reserve generation. To accurately assess the contribution of demand response such studies must be supported by realistic assumptions on consumer participation. A systematic review of international evidence on trials, surveys and programmes of residential demand response suggests that it is important that these assumptions about demand response are not overly optimistic. Customer participation in trials and existing programmes is often 10% or less of the target population, while responses of consumers in existing schemes have varied considerably for a complex set of reasons. Relatively little evidence was identified for engagement with more dynamic forms of demand response, making its wider applicability uncertain. The evidence suggests that the high levels of demand response modelled in some future energy system scenarios may be more than a little optimistic. There is good evidence on the potential of some of the least 'smart' options, such as static peak pricing and load control, which are well established and proven. More research and greater empirical evidence is needed to establish the potential role of more innovative and dynamic forms of demand response.

Keywords: Demand response; decarbonization; modeling assumptions; residential consumers.

1 Introduction

Many scenarios that explore how to decarbonise future energy systems envisage an increasing role for demand response (DR), sometimes also referred to as demand side response [1]. Demand response involves achieving changes in electricity demand at different times – for example, shifting demand from peak to off-peak demand periods. This may be achieved through price signals, automation of appliances, direct control of particular loads, information, or some combination thereof, see for example [2–4]. Demand response is not a new concept, but in most countries it plays a limited role and electricity supply and demand are balanced mainly by ensuring that generation, reserves, and network capacity are sufficient to meet demand [5]. Many future scenarios envisage large scale electrification of heat and transport, which account for very significant fractions of total energy consumption internationally. Electric heating and transport will create new challenges and opportunities through increases in total and peak electricity demand, as well as the challenges associated with managing electricity systems which include much higher penetrations of wind, solar and nuclear generation [5,6].

System modelling studies indicate that demand side flexibility can significantly reduce the need for network upgrades, peaking plant and ancillary services [7]. For this reason the value of demand flexibility is gaining prominence in policy reports [8,9]. In Europe, the majority of theoretical potential for demand response lies with residential consumers [10]. Whilst the potential role of energy storage including batteries and their possible contribution to electricity system management is likely to be important in the future, their current role in the domestic context is limited. This paper is therefore focused on the international evidence on domestic consumer participation in DR trials, programmes and surveys, and considers this with reference to the role of consumer demand response in modelling studies.

Modelling studies that explore the *value of* demand response should not be conflated with analysis of the *potential for* flexibility from the demand side. The value might be assessed through a system modelling study whilst the potential might be evaluated through a customer survey or engineering evaluation of particular types of automation or load. Nevertheless the two topics are clearly linked, because it is important that the potential for DR is not overestimated in models because of unrealistic assumptions about consumer engagement. For this reason this paper investigates the empirical evidence on the level of demand response achieved in a wide selection of international trials and programmes, incorporates relevant data from surveys on consumer attitudes to DR and asks: are modelling studies realistic about how much demand response we can really expect from domestic consumers?

The remainder of the paper is structured as follows: Section 2 describes the approach; Section 3 reviews key concepts in the DR literature; Section 4 presents our principal findings on consumer engagement with DR; Section 5 presents judgements about DR made in a sample of modelling studies; Section 6 discusses the findings from Sections 4 and 5, and Section 7 concludes.

2 Methodology

The evidence on which this paper is based was drawn from the results of a rapid evidence assessment (REA), a constrained form of systematic review of academic and grey literature [11,12]. A wide ranging review of the international literature on demand response trials, programmes and surveys was undertaken and the findings categorised. Systematic searches of academic and grey literature sources sought to identify a comprehensive (though not exhaustive) selection of reports detailing consumer enrolment and participation in DR, consumer response rates and whether consumers remained enrolled and engaged through time (see below for more details). Details of the approach to the review are presented in Appendix A. Specific search terms were also used to identify a sample of modelling studies that made assumptions about the nature and level of demand response. Sixteen papers were selected from the review results and their characteristics are summarised in Table 4. Appendix B presents the trials, surveys and programmes revealed through the evidence assessment.

3 Characterising demand response

Assuming demand response is voluntary rather than imposed through regulation, it must achieve consumer engagement in order to be realised. Analysts and modellers may expect consumers to respond predictably to price signals, accept home automation, and engage in largely planned and predictable household activities that facilitate a response [13]. However, consumer participation in demand response may not follow these expectations. For example, [14] suggest that consumers have limited knowledge of the potential benefits of DR, and that electricity is typically a routine and passive purchase that is not altered unless consumers are actively dissatisfied.

These factors may lead to consumers not taking up DR opportunities, either by not enrolling in schemes or by enrolling but only offering limited responses, or to 'response fatigue' where consumers stop responding or withdraw from programmes. The U.S. Electric Power Research Institute (EPRI) divide consumer engagement into three categories: *participation* – the decision to enrol in a DR programme; *response* or performance[1] – the amount of load shifting that is provided by participants; and *persistence* – the decision to remain enrolled in the programme through time [15]. Section 4 of this paper summarises the evidence from trials and programmes under each of these categories, together with the factors that influence consumer participation and response.

Different forms of demand response are commonly classified according to whether time varying pricing is used to promote changes in electricity use, known as price based demand response, or consumers are rewarded for estimated changes in demand compared to a baseline level, known as incentive based demand response. A more limited number of schemes aim to use information to change demand, with no economic incentive at all. Types of demand response also vary by the timing, duration, frequency and predictability of demand response and by whether response occurs as a result of manual behaviour change, automation, or direct load control[2]. It is important to distinguish between *static* and *dynamic* interventions – that is those that might change continuously rather than according to a predetermined schedule, and between occasional events (demand peaks which occur a few times per year) and more frequent, usually diurnal, load shifting.

The classifications and the specific types of demand response discussed in this paper are outlined in Fig. 1 and Table 1.

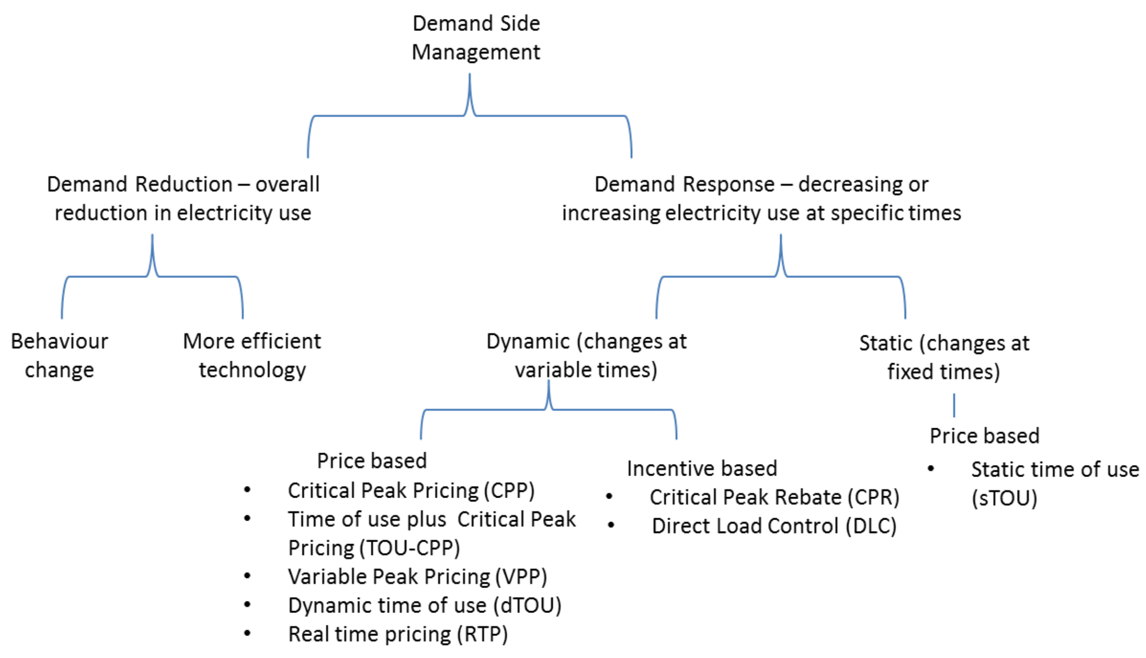

Fig. 1 Classifications of demand reduction and demand response (authors' own)

[1] EPRI use the term 'performance' but this paper generally uses the term 'response'.

[2] This is the use of signals from an external actor to control consumer appliances, an early example of which is the UK's radio teleswitch system, which uses a radio signal to control overnight storage heating and facilitate response to time of use tariffs such as 'Economy 7'[167]. DLC also has a long history in the US where it typically attracts incentive payments [2].

Price based schemes	Description
sTOU (static time-of-use)	Prices vary by time of day between fixed price levels and over fixed periods. These may vary by season.
CPP (critical peak pricing)	Prices increase by a known amount during specified system operating or market conditions. This applies during a narrowly defined period and is usually applied only during a limited number of days in the year.
TOU-CPP (time of use plus critical peak pricing)	Critical peak pricing overlaid onto time of use pricing. TOU-CPP therefore has two pricing components – daily time of use pricing, and occasional critical peak pricing applied during critical system events (Fig. 4 refers to these as TOU-CPP-D and TOU-CPP-CE respectively)
VPP (variable peak pricing)	Similar to time of use, but the peak period price varies daily based on system and/or market conditions rather than being fixed.
dTOU (dynamic time of use)	Prices vary between fixed price levels, but the timing of different prices is not fixed.
RTP (real time pricing)	Price can differ on a daily basis and change each hour of the day (or more frequently) based on system or market conditions.
Incentive based schemes	**Description**
CPR (critical peak rebate)	Similar to CPP, but customers are provided with an incentive for reducing usage during critical hours below a baseline level of consumption.
DLC (direct load control)	Customers are provided with an incentive for allowing an external party to directly change the electricity consumption of certain appliances. Customers can usually override control although they may lose some incentive. DLC may also be combined with time varying pricing.

Table 1 Types of pricing and other economic incentives discussed in this paper (authors' own)

Sections 4 and 5 of this paper consider the relationship between participation, response and persistence and each of these categories of DR, as well as the types of load shifted and other relevant factors, in both real world programmes and trials and in models.

4 Evidence on residential consumer engagement with demand response

The evidence review revealed 83 residential demand response schemes, of which 19 were established programmes and 64 were trials. The review also includes 11 studies based on surveys, focus groups or interviews that offer complementary insights. The evidence base is drawn from 18 countries, including the US, Canada, Australia, New Zealand, the UAE, and several countries in Europe. 63% of the evidence is from North America and 30% from Europe. In what follows we report findings primarily on a per trial/programme basis, discussing participation, response and persistence rates. Evidence from trials and programmes is reported on a findings per-scheme basis and reports of trials and programmes are referred to as 'studies'. Additional insights from surveys and focus groups are also included as appropriate and where quantitative findings are available these are also referred to as studies[3]. The high level view we provide gives a preliminary indication of the evidence base available on customer engagement with DR. Additional research could apportion findings on a per capita basis, distinguish further between trials and programmes, and provide additional geographical or historical detail. Further details of the review findings are provided in Appendices B to E.

We first present high level findings on participation, response and persistence, sections 4.1-4.3. Later sections discuss explanatory factors and the load types used for DR.

4.1 Participation – recruitment rates for DR trials and programmes

Of the 94 studies identified in the review only 28 reported on recruitment levels. As Fig 2 shows, reported recruitment rates vary widely from 2% to 98% of the target population. Some of this variation can be explained by whether customers were solicited for voluntary participation (opt-in) or were placed onto the trial or programme by default (opt-out); and the type of opt-in strategy used. Perhaps unsurprisingly, high recruitment rates were reported by studies utilising opt-out recruitment. Opt-out recruitment may be a way to increase participation in demand response, but as we explain below, the evidence reviewed suggests that in aggregate, customers participating in schemes recruiting through opt-out recruitment exhibit lower average responses than participants who opt-in to demand response schemes.

Reported opt-in recruitment rates varied widely, but just over half of the studies identified secured participation from 10% or less of the target population [16–28]. In some cases active engagement may be lower than the percentage enrolment numbers suggests: for example, one study suggests that around 40% of UK residential consumers enrolled in time of use tariffs such as Economy 7 and Economy 10 may be unaware of the tariff structure and fail to shift loads, probably as a result of having inherited the tariff from previous occupants [29]. Fig. 2 provides an overview of findings revealed in the evidence review, showing the variation in recruitment rates by opt-in and opt-out recruitment for 28 trials and programmes comprising 29 reported recruitment levels.

[3] The studies are identified firstly by naming the utility or other organiser, or the location of the study where this is more appropriate. The name of the study follows in speech marks and is the name given to the study by the organisers where known, otherwise it is a description of the trial. As well as being referenced throughout the text, Appendix B includes a summary of trials reviewed, with references, in alphabetical order.

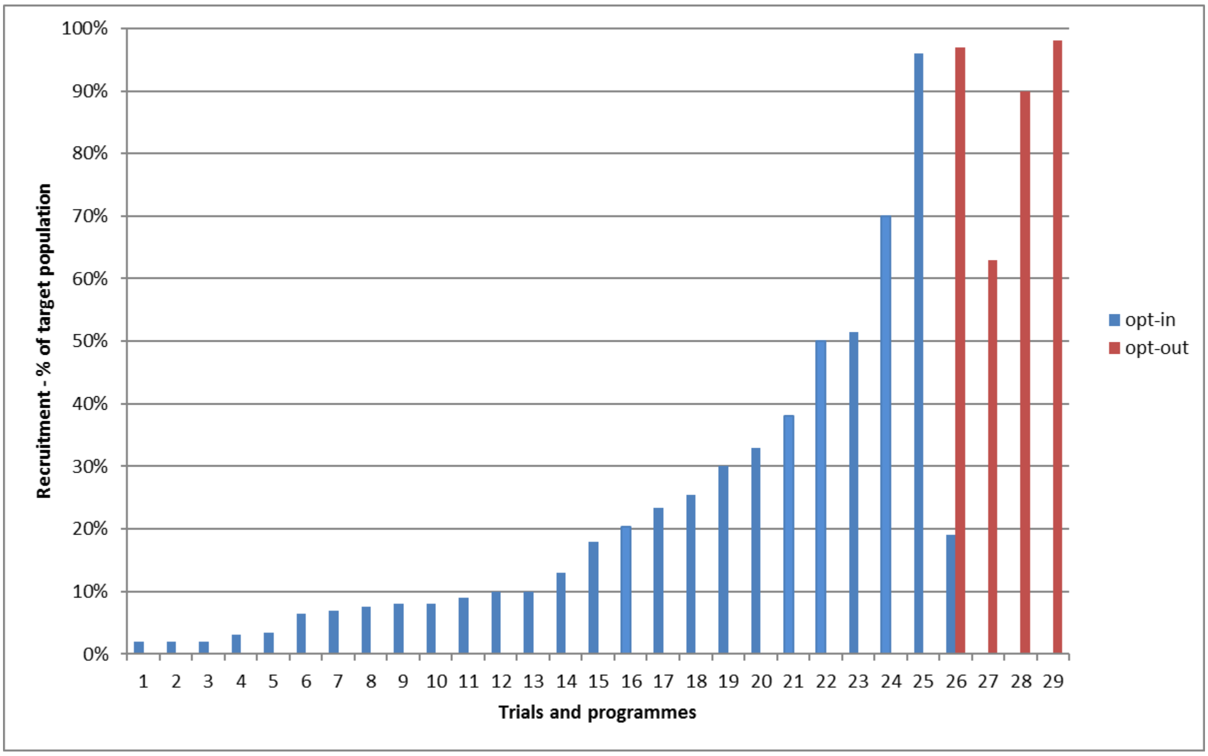

Fig. 2 Reported recruitment using opt-in and opt-out recruitment strategies[4]

Expanding on Fig. 2, Fig. 3 presents recruitment rates according to demand response type, for both opt-in and opt-out recruitment. The SMUD "SmartPricing Options" and Green Mountain Power "eEnergy Vermont" studies represent particularly interesting examples because they included multiple demand response types within the respective programmes. Therefore, to facilitate easier comparison between response types within these two studies, in Fig 3 recruitment levels for these trials are labelled ‘A’ for SMUD "SmartPricing Options" and ‘B’ for Green Mountain Power "eEnergy Vermont". Note that some studies which are shown in Fig. 2 are not included in Fig. 3 because the study included multiple types of demand response but only an overall recruitment rate could be identified.

[4] **Note to Fig. 2**
1: SCE "Summer Discount Plan" [16]; 2: DTE "Smartcurrents" [17]; 3: EDF "Tempo" [18]; 4: CL&P "Plan-it wise pilot" [19]; 5: First Energy "Consumer Behavior Study" [20]; 6: SMUD "Residential summer solutions" [21]; 7: ConEd "CoolNYC" [22]; 8: PG&E "smart rate" [23]; 9: PG&E "smart AC" [24]; 10: UK "CLNR" [25]; 11: Marblehead Municipal "energysense" [28]; 12: ComEd "Energy smart pricing plan" [26]; 13: Denmark "DR by Domestic Customers using Direct Electric Heating " [27]; 14: UK "Economy 7" and "Economy 10" [29]; 15: PG&E "DR contingency reserves trial" (direct phone call) [24]; 16: California "SPP" [101]; 17: BGE "Smart Energy Pricing Pilot" [99]; 18: Ontario "smart price pilot" [42]; 19: Ireland "CBT" [55]; 20: SCE "DR contingency reserves trial" [16]; 21: PG&E "DR contingency reserves trial" (door to door) [24]; 22: Norway "EFFLOCOM trial" [18]; 23: Green Mountain Power "eEnergy Vermont"[110]; 24: Netherlands “Your Energy Moment” [34]; 25: Laredo "Customer Choice and Control trial" [31]; 26: "SmartPricing Options" SMUD [35]; 27: Newmarket Hydro “TOU Pricing Pilot” [45]; 28: Ontario "TOU regulated price plan" [44]; 29: ComEd "CAP" [49].

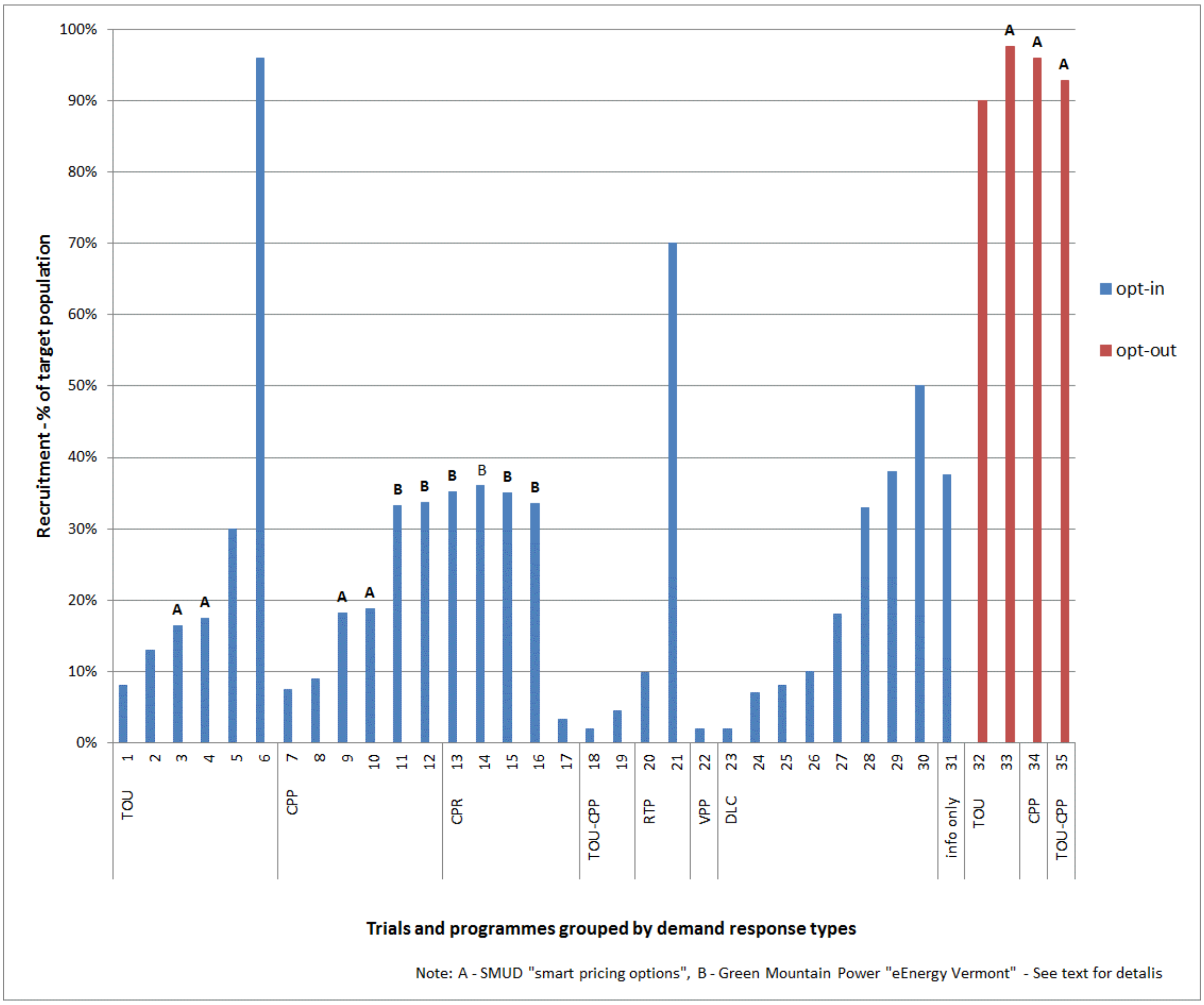

Fig. 3 Reported recruitment by type of demand response[5]

Opt-out recruitment rates are consistently high across the range of demand response types for which results were identified. For opt-in recruitment there is considerable variation in recruitment

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[5] **Note to Fig. 3**
1: UK "CLNR" [25]; 2: UK "Economy 7" and "Economy 10" [29]; 3: SMUD "SmartPricing Options" (TOU) [35]; 4: SMUD "SmartPricing Options" (TOU+IHD) [35]; 5: Ireland "CBT" [55]; 6: Laredo "Customer Choice and Control trial" [31]; 7: PG&E "smart AC" [24]; 8: Marblehead Municipal "energysense" [28]; 9: SMUD "SmartPricing Options" (CPP+IHD) [35]; 10: SMUD "SmartPricing Options" (CPP) [35]; 11: Green Mountain Power "eEnergy Vermont" (CPP) [110]; 12: Green Mountain Power "eEnergy Vermont" (CPP+IHD) [110]; 13: Green Mountain Power "eEnergy Vermont" (CPR+IHD) [110]; 14: Green Mountain Power "eEnergy Vermont" (CPR) [110]; 15: Green Mountain Power "eEnergy Vermont" (CPR, later offered CPP) [110]; 16: Green Mountain Power "eEnergy Vermont" (CPR, later offered CPP, + IHD) [110]; 17: First Energy "Consumer Behavior Study" [20]; 18: DTE "Smartcurrents" [17]; 19: SMUD "Residential summer solutions" (TOU-CPP) [21]; 20: ComEd "Energy smart pricing plan" [26]; 21: Netherlands “Your Energy Moment” [34]; 22: EDF "Tempo" [18]; 23: SCE "Summer Discount Plan" [16]; 24: ConEd "CoolNYC" [22]; 25: PG&E "smart AC" [24]; 26: Denmark "DR by Domestic Customers using Direct Electric Heating " [27]; 27: PG&E "DR contingency reserves trial" (direct phone call) [24]; 28: SCE "DR contingency reserves trial" [16]; 29: PG&E "DR contingency reserves trial" (door to door) [24]; 30: Norway "EFFLOCOM trial" [18]; 31: Green Mountain Power "eEnergy Vermont" (information only) [110]; 32: Ontario "TOU regulated price plan" [44]; 33: SMUD "SmartPricing Options" (TOU) [35]; 34: SMUD "SmartPricing Options" (CPP) [35]; 35: SMUD "SmartPricing Options" (TOU-CPP) [35].

rates within each type of demand response, and no obvious pattern in rates of recruitment across different types of demand response. However, within single trials (Green Mountain Power "eEnergy Vermont" and SMUD "SmartPricing Options") rates of recruitment to different types of demand response are very similar for opt-in as well as opt-out recruitment. This suggests that the context and strategy for recruitment may be more important determinants of recruitment rates than characteristics of different types of demand response.

Higher opt-in recruitment rates may result from more expert recruiters [30], more resources devoted to face-to-face marketing such as door-to-door recruitment, local meetings or workshops [16,24,30,31], and the involvement of trusted organisations [25]. Schemes with a more local nature have features that may encourage higher participation, such as facilitating the use of known and trusted local parties to support recruitment [32], and creating a sense of community in local or regional projects [33,34].

4.2 Response

The review revealed 52 studies providing information on response, drawn from 40 trials and 12 programmes. For the most part, the evidence found in the review is focused on response in the form of demand reductions but one study of dynamic pricing reported demand increasing with high wind output. Levels of response vary widely from over 80% reduction in reference load to practically zero. This subsection focuses on the extent to which the *intended* effects of DR are delivered by consumers. Some of the studies examined also reported unintended effects, for example, critical peak pricing resulting in daily load shifting as well as a response during critical peak events; ‘snap back’ of load after the end of a peak, or a second peak that is higher than the first. Studies also reported both increases and decreases in overall electricity use.

Fig. 4 summarises the evidence base on how consumers respond to different forms of demand response, grouped by the basic treatment type (that is, different structures of time varying pricing, direct load control, or information only). The figure aggregates the number of studies for each type of intervention and the range of findings on response levels across studies. Due to the volume of data, individual studies are not identified in the figure, although the number of studies from which data are drawn for each category of intervention are shown next to each range bar. The figure also represents something of a simplification in that studies report using a range of metrics – for example some consider peak power, others energy during peak periods and some do not specify (see note to Fig. 4).

Relatively little evidence was identified for consumer engagement with more dynamic forms of response (dynamic time-of-use and real time pricing). As a result there is more uncertainty about these forms of intervention, in terms of how widely applicable the response ranges may be in different contexts and how significantly they are affected by factors such as automation, price, appliance type and climate.

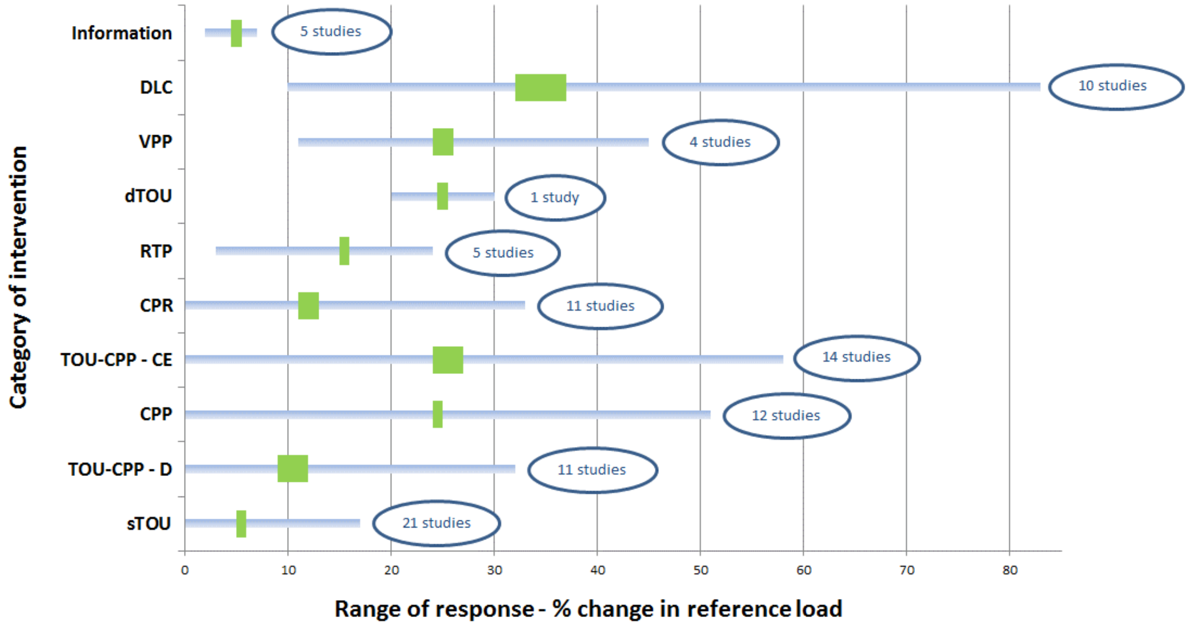

Fig. 4 Summary of reported responses, grouped by treatment type[6]

4.3 Persistence

The extent to which enrolment and response persist over time is an important question for planning the contribution residential DR could make to electricity systems [35]. It is possible that either response or enrolment may change over time as, for example, demand response participants learn to respond more effectively [36], or become fatigued and stop responding or leave the trial or programme [14]. Table 2 summarises changes in enrolment and response for the 10 trials and 10 programmes that reported these across two or more years. Taken together, these do not suggest a clear trend for enrolment or response to change over time. It could be assumed that certain types of demand response are linked to higher or lower levels of persistence; for example, consumers might find it more difficult to respond to more dynamic pricing such as real time pricing or variable peak pricing and as a result persistence may be lower for such forms of demand response. To assess this, Table 3 presents changes in enrolment and response by demand response type wherever this was reported. Again, these results do not suggest a clear trend for changes in enrolment or persistence according to demand response type.

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[6] **Note to Fig. 4.**

Fig. 4 presents reported change in reference load and includes studies reporting change in peak energy or power, the most common metrics for response identified in the review. Some reported responses as a percentage change without being clear whether this referred to power or energy. Results presented in units other than percentage change in peak energy or power are summarised in Table C1 in Appendix C. Energy and power are not equivalent and Fig. 4 seeks only to report the range of findings on response reported in the literature. In almost all cases response refers to the percentage *reduction* in the reference load, but one dynamic time of use (dTOU) study reports a 30% *increase* in demand at low price periods, simulating increased use of wind generation, as well as 20% reduction in demand during high price periods. If a study reported more than one result, for example if it included different types of demand response or average responses for different times of year, every reported result was included. In some cases direct load control was combined with time-varying pricing, and reported responses are included under both sections. Acronyms as per Table 1. See Appendix B for full list of references.

	Enrolment over time			Response over time		
	increase	decrease	stable	increase	decrease	stable
Trials	1	1	4	2	3	5
Programmes	6	1	1	1	3	6

Table 2 Persistence of enrolment and response in trials and programmes across two or more years

		Enrolment over time			Response over time		
		increase	decrease	stable	increase	decrease	stable
Trials by DR type	TOU					1	3
	CPP						2
	TOU-CPP	1		1	2	1	3
	CPR						
	VPP	1			1		
	RTP						
	DLC		1			1	1
	Information only						1
Programmes by DR type	TOU	1					1
	CPP	1				1	
	TOU-CPP						
	CPR	1					2
	VPP						1
	RTP	1					1
	DLC	2	1	1	1	2	1
	Information only						

Table 3 Persistence of enrolment and response in trials and programmes by type of demand response across two or more years[7]

Appendix D presents the findings for each of these studies, and whether response/enrolment levels were 'stable' (defined as changing 10% or less across the reported period, or a description that response/enrolment were stable), increased, or decreased. Summarising changes over the whole time period reviewed does not indicate the size of changes within this period but these are partly presented in Appendix D. Differences between the trials and programmes summarised in Table 2 contribute to changes in enrolment and response and mean the results are not fully comparable. Recruitment efforts may decrease as a result of regulatory uncertainty surrounding a programme, for example [37], while reported response could be influenced by changes in strategies for triggering demand response and/or changes in temperature or other factors influencing baseline demand, for example [38,39]. Enrolment increases in programmes reflects ongoing active recruitment, particularly for new programmes: for example, the Ameren Illinois "Power Smart Pricing" programme saw participant numbers increase from 500 in 2007 to over 13,000 in 2013 [40,41].

4.4 Factors affecting engagement with Demand Response

The evidence reviewed reveals significant variation in participation and average reported responses. Understanding the reasons behind this will clearly be important to assessing the contribution demand response could make to electricity system flexibility. A number of factors were identified in the literature that may affect response rates, and these are described below.

[7] A number of trials included more than one type of demand response, and are counted in more than one cell of table 3. Two trials did not report on enrolment over 2 or more years by demand response type, and so these results are omitted from table 3.

4.4.1 Automation technology & real time information

In general, if participants have access to additional information (for example, in-home displays indicating current price levels) or automation technology, average responses are greater than those for pricing alone. Trials that tested automation and information alongside pricing reported responses that were on average 2.5% higher with additional information, and 15% higher with automation technologies, compared to responses with neither technology. Responses with both additional information and automation were on average 13% higher compared to responses to pricing only. The impact of automation and information on responses varies between trials – the range for automation is -4.7% to 31.9% and for information is -1.1% to 6.8% (Appendix E).

4.4.2 Appliance ownership and climate

Larger responses would be expected where baseline electrical demand is higher, and this was generally found to be the case. Customers with air conditioning or electric heating generally showed larger responses than customers without these typically larger electrical loads, while responses were larger during periods of higher summer temperatures (and by implication, greater air conditioning use). Seasonal variations in overall response present a more complex picture, with responses being lower in winter for studies based in Canada but higher in winter for studies based in Sweden and New Zealand. Some Canadian participants reported finding it harder to respond in winter than summer [42]. These differences seem likely to relate to whether participants feel able to use their appliances flexibly rather than the total electricity demand at a certain time. Fig. 5 presents reported response levels for trials and programmes comparing these load and seasonal factors.

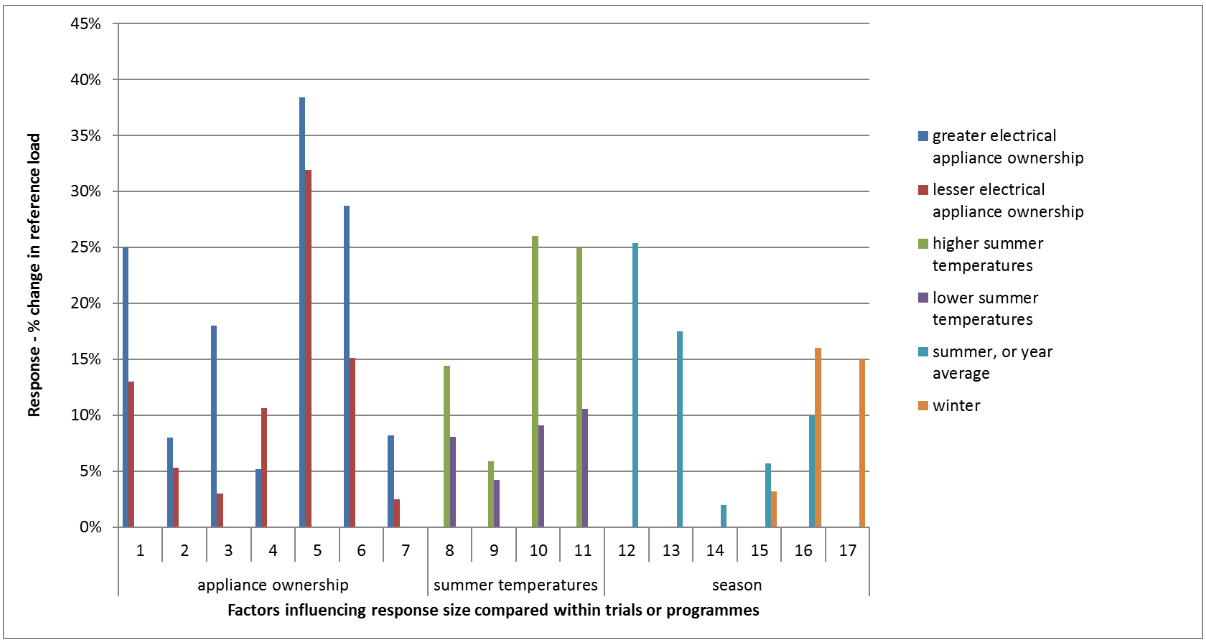

Fig. 5 The influence of appliance ownership, summer temperatures and season on reported response levels[8]

[8] **Note to Fig. 5**

1: Powercents DC, CPP [46]; : Powercents DC, CPR [46]; 3: Powercents DC, RTP [46]; 4: Xcel "energy pilot", TOU [43]; 5: Xcel "energy pilot", CPP [43]; 6: Xcel "energy pilot", CPP-TOU, peak [43]; 7: Xcel "energy pilot", CPP-TOU, daily [43]; 8: California SPP, CPP [101]; 9: California SPP, TOU [101]; 10: DTE "smart currents" TOU-CPP + PCT, daily [17] 11: DTE "smart currents" TOU-CPP + IHD + PCT, daily [17] 12: Ontario “smart price pilot", CPP [42]; 13: Ontario/Hydro Ottawa “smart price pilot", CPR [42]; 14: Ontario/Hydro Ottawa “smart price pilot",

4.4.3 Opt-in vs opt-out

In general, customers enrolled through opt-out recruitment appear to be less responsive on average than customers who opt-in and volunteer to participate. Fig. 6 presents reported responses for three studies that directly compared average response associated with opt-in and opt-out recruitment. In each case the average response of customers who opted in was higher. Other studies included opt-out recruitment only. The ComEd "CAP" trial identified no significant response overall. However, six other studies that tested opt-out recruitment did report an overall response [43–48].

Because opt-in and opt-out recruitment is likely to influence enrolment as well as response, it may be particularly helpful to consider studies that consider the aggregate change in demand, accounting for the number of consumers enrolled as well as the average percentage response by those consumers. Analysis of the ComEd "CAP" trial identified a sub-group of 'event responders', representing around 10% of total participants, who exhibited load reductions in line with customers opting-in to similar pricing in other studies. This analysis suggests that opt-in and opt-out recruitment may give rise to similar aggregate responses overall [49]. Further analysis of the SMUD "smart pricing options study" identified three sub-categories within the opt-out recruitment group: those who would likely have opted-in, those who opted-out, and "complacents" who would likely not have opted-in, but did not opt-out. While around 20% of "complacents" exhibited no measurable response, a larger group of "complacents" exhibited a small response, and another group exhibited a substantial response. Unlike [49], this suggests that opt-out recruitment increased the proportion of responding customers compared to opt-in recruitment. Extrapolating the results to all SMUD's residential customers suggests opt-out recruitment could reduce peak demand by 5.7% in aggregate compared to 3.3% in aggregate for opt-in recruitment [50]. Another study comparing responses to critical peak pricing implemented through opt-in and opt-out recruitment found that although opt-in recruitment led to lower enrolment than opt-out recruitment, it actually resulted in higher aggregate responses [51].

Taken together this evidence suggests that although opt-out recruitment can lead to higher participation, average responses across enrolled customers are likely to be lower than for equivalent opt-in groups. The results reveal no clear trend in aggregate response with opt-out compared to opt-in recruitment and suggest that in different circumstances this may be similar to, larger, or smaller than aggregate response with opt-in recruitment.

TOU [42]; 15: Ontario "TOU regulated price plan" [44]; 16: Sweden "Sala Heby Energi Elnait AB" [142]; 17: Mercury Energy "TOU trial" [56]

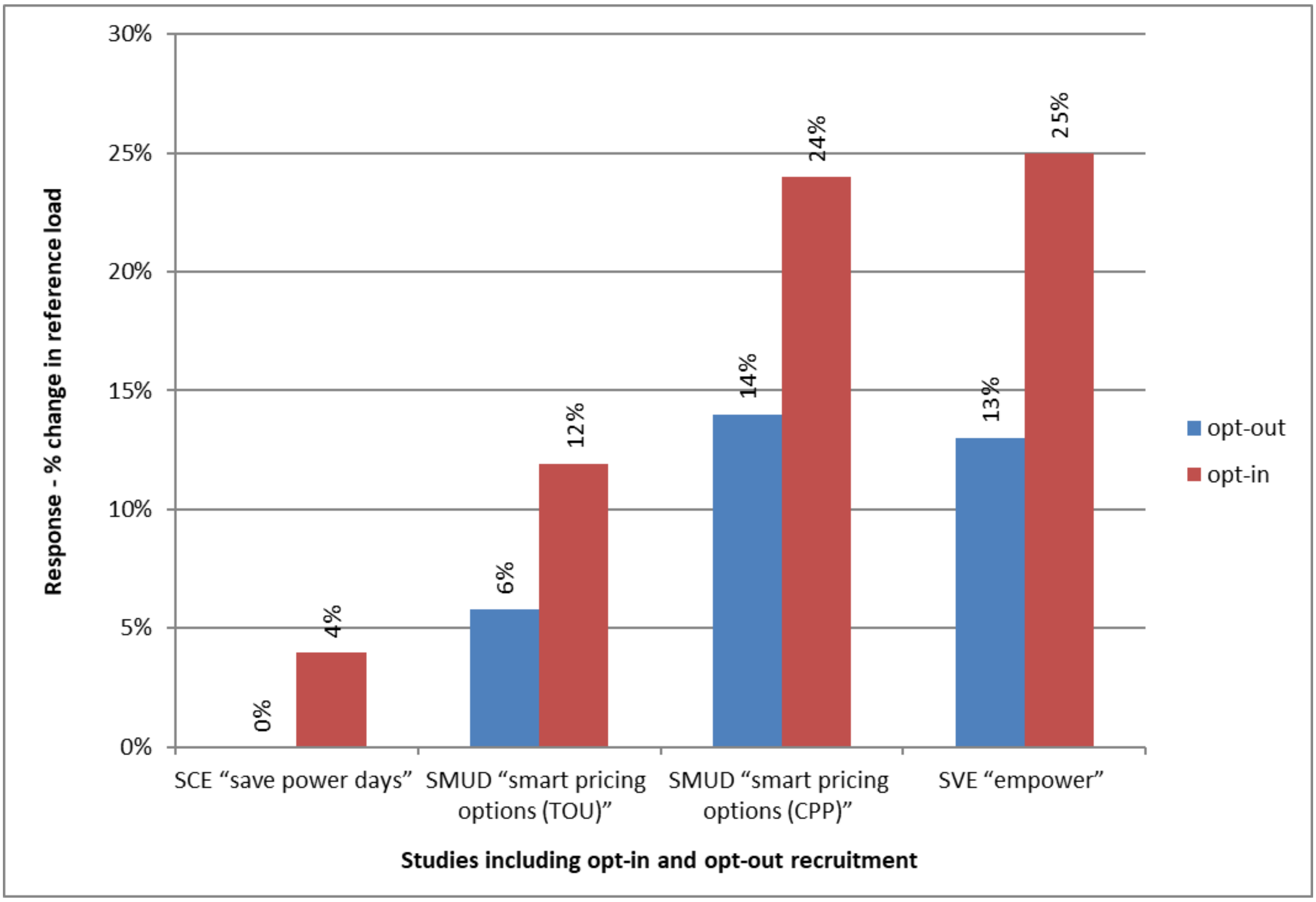

Fig. 6 The impact of opt-in and opt-out recruitment on reported responses [35,52,53]

4.4.4 Price ratio

It may be assumed that greater financial differentiation between peak and off-peak periods when DR is or is not required should result in greater responses by consumers, but the evidence reviewed presents a more complicated picture. Five studies tested different peak to off-peak price ratios. Two of these (BC Hydro and GPU trials) identified greater responses where price ratio was higher [43,54]. However, the other three (Ireland “CBT”, Mercury Energy “TOU trial” Danish “DLC trial”) reported that different price or rebate levels made no difference to the level of response [27,55,56].

Some analyses compared the impact of price ratio across different studies. [57] found that 37% percent of the variation in average response for 34 studies can be explained by the combination of price ratio and enabling technologies such as automation or information through in-home displays. [58] analyse critical peak pricing and time-of-use pricing separately, since these forms of demand response typically differ in price level, frequency, and the presence of event notifications for CPP. These authors conclude that when CPP and TOU tariffs are analysed separately there is no clear trend for higher price ratios to result in larger reported responses. However, [57] find that both price ratio and enabling technologies have a strong relationship with demand reduction for TOU pricing, although for CPP enabling technology has a greater impact than price.

4.4.5 Level of commitment by organisers

It is possible that the level of commitment to demand response by trial and programme organisers could influence their level of effort to engage with customers, and hence the levels of enrolment and persistence that they achieve. Whilst it is not straightforward to identify levels of motivation in many of the studies identified in the review, some do suggest higher or lower levels of commitment by the organiser. For example, at the time of the ComEd "Energy smart pricing plan" trial, ComEd was prohibited by law from offering new electricity tariffs so in order to conduct the trial, they partnered with a local non-governmental organisation [26]. This suggests a relatively high level of motivation by ComEd to explore or pursue demand response. Conversely, some organisers pursue demand response because they are required to do so by regulation, for example [59], and in these circumstances it is not clear how enthusiastic the organisers are.

There were also a range of intentions for conducting the studies identified in the review. There are examples, such as [60], of studies reporting the performance of established programmes; pilot studies undertaken to evaluate demand response options the organiser is considering rolling out in the near future, such as [36]; and proof-of-concept trials for more novel forms of demand response, such as [16]. It may be more straightforward to identify study intentions than organiser commitment to demand response. However, it does not necessarily appear to be the case that studies not intended to explore real-life implementation of demand response are associated with less effort to engage consumers. If studies are carried out on relatively small scales it is possible this may actually enable more intensive recruitment strategies such as face-to-face recruitment, as in [16], for example.

5 Demand response in modelling studies

This section summarises the assumptions made in a sample of 16 modelling studies revealed through the evidence review. It includes participation and response rates, forms of demand response, and types of electrical loads involved. Only participation and response are discussed here because none of the studies discuss persistence. It is important to be clear that the objective is not to show that the models are 'wrong', since many models seek to explore potentials and prospects rather than to represent findings from trials or programmes. Rather the purpose is to provide a fact base on what aspects of consumer participation are explicit in modelling studies and which are not. Table 4 summarises the principal assumptions found in the review of modelling studies.

Study	Assumed demand response type	Assumed participation (% of target population)	Assumed electrical loads participating in demand response
[61]	Automation	100%, 75%, 50% and 25%	Refrigerators
[62]	Real time pricing	70%	Heat pumps and electric vehicles
[63]	Not specified	100%	Electric vehicles
[64]	Automation	100%	Washing machines, dishwashers, tumble dryers, electric vehicles.
[65]	Not specified	Not specified	Not specified

[66]	Not specified	Not specified	Dishwashers
[67]	Automation	6% [A]	Electric water heating (immersion heaters).
[68]	Static time-of-use PLUS dynamic pricing or automation for wind supply following	16% (static time of use), 15% (wind following).	Cold and wet appliances, water and space heating.
[69]	Real time pricing	Not specified	Not specified
[70]	Direct load control PLUS static time-of-use pricing	100%[B]	Electric water heating
[6]	Not specified	Not specified	Heat pumps with thermal storage, and electric vehicles.
[71]	Automation PLUS real time pricing	100%	Various appliances
[72]	Automation	100% [C]	Dishwashers, washing machines, tumble driers.
[73]	Not specified	20%	Refrigeration (prototype using phase change materials to increase thermal storage)
[74]	Automation	Not specified	Heat pumps
[75]	Not specified	Not specified	Not specified

Table 4 Assumptions made by modelling studies featuring residential demand response[9]

5.1 Participation

Around a third of the modelling studies reviewed assume a very high level of consumer participation in demand response, with four studies explicitly specifying that 100% of the modelled load can be shifted (although for one study this is specified for all white good cycles and implied for electric

[9] **Notes to Table 4**

A: [67]: model 100,000 electric water heaters. Assuming every household has one electric water heater, 100,000 water heaters represents around 6% of households identified in the 2011 census.

B: [70]: The authors do not state 100% participation, but explain: 'There are approx. 1.36 million EWHs in this region… This data has been scaled for use with the 1,000 EWHs in our study' (pg. 772).

C: [72]: Assumes 80% of consumers have smart dishwasher, 75% have smart washing machine, and 25% have smart washer-drier, referring to ownership rates for standard appliances.

vehicle charging) [61–64]. [71] model 75% of consumers shifting wet and cold appliances at a lower price threshold, but 100% during critical peak periods. [72] assume that 80% of consumers have a smart dishwasher, and 100% have some form of smart washing machine (25% of these having a washer-drier). [62] assume 'a suitable control system…in about 70% of electrically heated homes'.

Whilst other modelling studies do not clearly specify the percentage of load participating, they do appear to suggest that it is relatively high. For example, [6] discuss the additional load that would result from full penetration of electric vehicles and heat pumps, appearing to show all additional load is re-distributed according to the optimisation process. [66] review statistics on total appliance ownership by households, and then model the impact of load shifting by these, but it is not clear whether the modelling covers total appliance ownership. [65] state that although response to price is voluntary, it is assumed that customers will respond, although it is not clear whether this means 100% of customers in the modelled system will participate in DR, or 100% of customers who choose to participate will actually respond. [69] state that 'loads are assumed to be responsive with respect to price' (pg. 4). [74] state that their model represents 'a large population' of heat pumps (pg. 4), but do not state the total number of consumers these represent.

Lower participation levels are modelled by [61], who model 100%, 75%, 50% and 25% participation by UK residential refrigeration, and [73], who model participation of 0-100% of commercial and residential refrigeration, and quote benefits assuming 20% participation. [68] assume 16% of households participate in TOU shifting, and 15% of total domestic loads participate in supply following (although if less than 100% of load is assumed to be flexible, this would represent more than 15% of households). Similarly, [75] assume '0.1p.u.' (per unit) of load is flexible, but as the type of load is not declared it is not possible to know what percentage of the population this represents. [67] model 100,000 aggregate water heaters in the electricity system of the Republic of Ireland, which, if every household has one electric water heater, represents around 6% of the households identified in the 2011 census.

5.2 Response

Overall, while the studies reviewed generally take care to establish the technical basis for load shifting (for example, identifying every journey made by light vehicles in the UK, or modelling fridge duty cycles), they do not obviously consider the extent to which consumers might actually engage with the interventions modelled. One exception is the modelling study by [72] , which takes its assumptions about participation and acceptable load shifting times from a survey of European customers [76]. In some cases the possible range of consumer preferences is acknowledged, but is not incorporated into the model: [70] suggest that consumers should have the option of overriding control, but do not model the impacts of this; [65] note that customer response is voluntary, but assume that customers always respond; [74] note that customers may be unwilling to hand over control of their thermostats, but assume that the economic incentive will be sufficient for them to do so. [63] note that electricity price differentials may be insufficient for consumers to shift load, but assume they will shift load even when the economic incentive to do so is low.

5.3 Factors affecting engagement with Demand Response

5.3.1 Forms of DR in represented in models and the role of automation or DLC

Three modelling studies reviewed, [62], [69] and [71], specifically include real time pricing. Others suggest that price or economic incentives would be used to control loads, but without specifying the price or incentive structure [63,65,66]. [68] model two components of DR, namely peak shifting in response to TOU pricing, and wind supply-following which the authors suggest could be dispatched by direct communication, autonomous response or price signals. In [6] the load is shifted according to an optimisation algorithm, but it is not specified how this is communicated to customers.

The majority of the modelling studies reviewed include some form of automation. In [67], [70] and [74], this takes the form of changing temperature set points on programmable communicating thermostats (PCTs) for space or water heating. [72], [73], [71] and [61] model smart appliances that can either be controlled externally or respond autonomously to system conditions. Others are less specific, with [64] describing load shifting as being 'centrally optimised' rather than price based, suggesting the use of direct load control, whilst [75] suggest the use of direct load control but do not specify which loads are controlled, and [62] suggest that automation would be used to facilitate consumer response to real time pricing.

Where automation/real time pricing is not specified it nonetheless seems likely to be required in order to achieve the dynamic responses described. Of the models reviewed, only [68] and [70] modelled the impact of simple TOU shifting, although [66] and [64] noted that their optimisations tended to shift demand to periods of low load. This could indicate that a less dynamic response could achieve at least some of the modelled benefits, although [64] note that the variability of optimum demand shifting increases with increasing variable renewable electricity, and [68] and [70] find that, alone, TOU shifting achieves lower benefits than dynamic shifting.

5.3.2 The types of loads shifted

The majority of modelling studies reviewed focus on the potential benefits from shifting a particular type of load. These included appliances types which consumers currently have little experience of, such as electric vehicles [6,62–64], and heat pumps [6,62,74]. Wet goods are modelled by [64,66,68,71,72], cold goods by [61,68,71,73]. Conventional electric water or space heating and conventional air conditioning are also modelled. [62] include manual shifting of appliances usually considered to be inflexible, whilst some studies, such as [65] and [75] do not specify the type of load modelled.

6 Discussion – comparing modelling assumptions and empirical evidence

6.1 Participation, response and persistence: real world vs models

The evidence reviewed suggests that some modelling studies make highly optimistic assumptions about residential consumer engagement with demand response. For example, participation rates are assumed to be between 70 and 100% for five out of the eight modelling studies which state their assumed participation, yet in real-world trials and programmes just over half of those studies that reported opt-in recruitment rates achieved overall recruitment of 10% or less of the target population. While opt-out recruitment can achieve enrolment rates of close to 100%, the percentage response across enrolled participants is likely to be considerably lower than for opt-in recruitment. More importantly in terms of electricity system management, the findings of this review revealed no clear trend for opt-out recruitment to increase aggregate response.

As we have suggested above, the intent, motivation, organisation and commitment of the range of actors involved in trials can vary significantly, and this can have very material implications for the level of demand response actually achieved. Similarly, the intent and objective of modelling studies will affect the results of such analyses. For example, at one extreme models may be used to explore the upper bounds of what is theoretically possible as opposed to assessing what outcomes are most likely based on observed levels of engagement and response in trials. This highlights the need to carefully assess the degree of alignment (or otherwise) in the motivations behind trials and modelling studies, and what that may mean for the validity of the assumptions underpinning modelling results.

The modelling studies reviewed tend not to explicitly state the level of response assumed. However, many make clear assumptions about the type of demand response. Eight of these include some form of automation, and three assume real time pricing or a similar dynamic price signal. There is reasonable evidence to support the assumption that some form of automation/DLC is accepted by at least some consumers, although the majority of evidence reviewed relates to direct load control of air conditioning during critical peak periods in North America. However, there is less evidence identified by the review to support the assumption that consumers would engage with more dynamic pricing, because most of the evidence comes from trials and programmes which offer static time of use or peak tariffs. Modelling studies acknowledge that voluntary responses may not always take place [65], that consumers may be unwilling to hand over control [74], or that price differentials may be too low to result in behaviour change [63], but there is a clear disconnect between studies that assume consumers will respond to dynamic signals and the evidence base examined for this paper.

Simply put, models tend to assume a high level of participation and response to dynamic price signals. Yet the evidence suggests that participation and response rates are at best highly varied and at worst quite low, and that there is very little experience with dynamic pricing. However this does not mean that demand response cannot provide many of the benefits discussed in modelling studies. Static load shifting between peak/off-peak periods could generate savings in wholesale electricity prices [77], and continue to be valuable in a future system with higher penetrations of wind generation [78]. It could offer greater benefits to consumers with electric vehicles or electric heating [79]. The relative simplicity of static time of use pricing may make it a good option to introduce demand response to consumers [80], while because it is more predictable, response levels for static load shifting may be modelled more accurately than for other forms of demand response.

The majority of the modelling studies specify the electrical loads involved in demand response, but there is considerable disconnect between the loads modelled and the empirical evidence. It seems unlikely that alternative electrical loads with different demand patterns will offer strong proxies for the loads of which there is as yet little empirical experience.

Five of the modelling studies reviewed featured wet appliances (washing machines, driers and dishwashers), and smart wet goods were specifically featured by five empirical studies and were commonly cited by trial or programme survey respondents as a load that was shifted in response to price. Other survey respondents generally stated that shifting wet loads would be acceptable, as long as routines were not disrupted and noise did not cause a disturbance at night, although some had additional concerns, and some may have overstated how they would actually behave - a concern particularly emphasised by [76].

Heat pumps were featured by three of the modelling studies, and heating and cooling were the most common loads targeted by empirical studies identified. Whilst heat pumps are technologically different from other heating technologies (and not yet widespread), it is possible that technical differences have been captured by the modelling studies and that consumer acceptance of shifting existing heating or cooling is analogous to acceptance of shifting heat pumps. The majority of empirical studies were based in North America, but examples were also found in Europe and elsewhere. The acceptability of shifting these loads may depend on factors such as the level of insulation, availability of alternative heat sources, or climatic conditions, but if these conditions are met the evidence suggest that it may be possible to shift these loads. However, some survey participants felt that these loads should be available on demand [76] and were already at the minimum levels for comfort [81].

Whilst wet appliances, together with heating and cooling are reasonably well represented in the evidence, of the other main loads featured by the modelling studies reviewed, electric vehicles do not feature in any of the trials or programmes included in our review, and barely featured in surveys either. Furthermore, it does not seem that other loads can be easily considered analogous to electric vehicles, since the energy services provided are quite different.

Finally, three of the modelling studies assume flexible operation of refrigeration [61,68,71]. This featured in only two of the demand response studies reviewed, namely Spain “ADDRESS project” [82] and DTE “smartcurrents” [17]. Surveys report mixed results on the acceptability of smart refrigeration, with some consumers stating it would be very acceptable, and others stating concerns about food quality and safety, which may persist despite assurances [76].

6.2 Evidence gaps and uncertainties

6.2.1 Response variability

Much of the evidence is concerned with *average* rates of participation and response. However it is also possible for response to vary relative to the average, through consumers changing a pattern of behaviour – for example if a substantial fraction of consumers overrode automated controls at the same time. This potential for response variability might influence the benefits that could be achieved from demand response. Variability in reported responses was not a factor that was explicitly investigated in the review, but certain studies reporting variable responses were identified. The UK “CLNR” trial of static time-of-use pricing found that although peak demand was reduced on average, this was not the case during the annual system peak [83]. Including automation as part of demand response will not necessarily avoid different patterns of behaviour leading to response variability, due to the potential for override and low use of automation. Participant override of direct load control may vary considerably, for example from 9–39% in the SDG&E “Smart Thermostat Pilot” [84] and from 21–31% in the ConEd Cool NYC programme [22]. If demand response is to displace alternative forms of flexibility then it appears likely to be necessary that any variability in response is understood and can be predicted with sufficient accuracy, otherwise uncertainty, risk and costs may increase [79,85,86].

6.2.2 Recruitment costs

Aside from the limitations of evidence on consumer engagement, there appears to be a lack of evidence on the costs of implementing demand response [87]. Expected technology costs are reviewed by [88], but not the cost of engaging consumers, which can be significant [32]. Such costs could include changing billing systems and the additional marketing required to recruit customers onto demand response tariffs [87]. If some forms of demand response can be relied on at certain times but not others the costs of any back-up management should also be considered when assessing the contribution demand response could make to electricity system management.

7 Conclusions

Residential demand response could offer various benefits as part of a low carbon energy system transition. By systematically reviewing evidence on residential consumer enrolment, response and persistence with international demand response trials and programmes this paper comments on assumptions made by studies modelling the potential of residential demand response.

Much of the evidence identified related to more traditional forms of demand response that aim to reduce peak demand and less evidence was identified for consumer engagement with dynamic forms of demand response and emerging new electrical loads such as electric vehicle charging. While understandable, this does at least raises the question as to the extent to which consumers will engage with more dynamic demand response in the future.

Reported opt-in recruitment rates varied widely across the evidence reviewed, but just over half of the studies identified reported recruitment of 10% or less of the target population. Perhaps unsurprisingly, high recruitment rates were reported by studies utilising opt-out recruitment. However, across the enrolled population, average responses tend to be lower where participants are recruited on an opt-out basis, while the absolute size of response may be similar across both opt-in and opt-out recruitment.

Average response levels vary between different types of demand response, but also show considerable variation within types. Varying average response levels are influenced by the presence of automation technology and real time information; baseline electrical demand linked to appliance ownership and season; and the ratio between peak and off peak electricity pricing or comparable incentives. However, it is not clear that these factors are able to explain all the variation in average response across different studies. In addition, some studies suggest that response levels may vary between different demand response events within a single trial or programme. Variability in response levels could make it more difficult to assess the potential contribution of demand response to electricity systems, and mean that demand response is unable to entirely displace other forms of electricity system management. Response levels at different times may be harder to predict for more dynamic forms of demand response.

Persistence in enrolment or response could change if demand response participants learn to respond better, or become fatigued and stop responding or leave trials or programmes. However, the evidence reviewed did not suggest a trend towards either outcome.

Overall, there is considerable evidence that at least some residential consumers are willing to participate in at least certain forms of demand response. However, any plans to increase residential demand response to provide greater flexibility in a decarbonising energy system should take careful account of the range of issues identified in the available evidence, including likely consumer engagement and the motivations of all actors involved. The evidence appears at present to be complex and somewhat mixed, and suggests that the high levels of demand response modelled in some future energy system scenarios may be more than a little optimistic. There is good evidence on the potential of some of the least 'smart' options, such as static peak pricing and load control, which are well established and proven. They may be able to offer many of the benefits sought in modelling studies. However, more research and greater empirical evidence is needed to establish clear guidelines for modelling of the potential role of more innovative and dynamic forms of demand response.

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Appendix A: Search approach

Evidence on residential consumer engagement with demand response

In all cases, citation trails from reviewed reports and papers were followed where it was felt that this would be productive. The search was confined to English language publications, and those which were available free of charge or through existing Imperial College journal subscriptions.

The literature review began by reviewing relevant references for HubNet smart metering position papers, and BEHAVE conference 2014.

Academic literature

The database Science Direct was searched using the following terms:

(pilot OR trial OR test) AND ("demand response") AND (residential OR "mass market" OR domestic) AND electricity

The results were filtered to journal articles, published after 1989.

The titles and abstracts of these results were used to select studies which appeared to include empirical evidence (including in the form of a review or meta-analysis), and which may have included residential customers. Some further results were then eliminated after consulting the full paper (the primary reason being that the title and abstract did not make clear that commercial or industrial response rather than residential response was under consideration).

Grey literature

The search engine Google was used to search the following terms:

(pilot OR trial OR test OR programme OR program) AND ("demand response" OR "demand side response" OR "direct load control") AND (residential OR domestic) AND electricity
The top 100 search results were reviewed, to select those that included, or made reference to, examples of empirical evidence of residential consumer experience of demand response. Many of the top 100 results consisted of sites of demand response vendors, or utility news sites, and so referred to examples of trials or programmes without including the results of these. In some cases, the name of the trial or programme was not clear (for example, only the utility or the location was referred to), and further Google searches were used to identify the names of trials and programmes.

Where these searches did not identify the empirical results of trials or programmes, further searches were made including the name(s) of the trial/programme, utility or organiser where known, and 'results' OR 'findings' OR 'evaluation' OR 'impact'. The top 10 results for each search were reviewed. Quantitative or qualitative results were noted, including those presented within reviews, provided that the review included details of the trial or programme. Where calculated costs and benefits were reported rather than the raw results, these were not included.

A large number of results were identified in the US, many of which comprised utility run-DLC programmes, and in some cases it was not clear that results were publicly available. Therefore, searching for results was restricted to cases where there was believed to be a high probability that results had been publicly reported and analysed. This included: programmes and pilots that had already been cited in the academic literature; programmes and pilots that had been undertaken in response to regulation on demand response or dynamic pricing (which the initial search results made reference to in Ontario, California, Illinois, Pennsylvania, New York, and Ohio); and those that had been undertaken in connection with, or analysed by public sector bodies or consultancies involved in demand response research.

A number of larger sources of evidence were identified in the top 100 search results, which were searched individually. These were Navigant, Vaasa Ett, Brattle Group, Ofgem, EPRI (whose results were limited to the past 5 years due to the large number), smartgrid.gov, and ec.europa.

Modelling studies illustrating potential benefits

Network

The database Science Direct was searched using the terms:

('demand response' OR 'demand side management') AND benefits AND ('network investment' OR 'network reinforcement')

The results were filtered for journals on the topics of energy or electricity, and for the topics of distribution networks or smart grids.

Results were then selected based on the abstracts, to include papers that described potential benefits of demand response (rather than, say, how DR may be impacted by regulation).

The database IEEE Xplore was searched with same search terms. Results were not filtered, and results selected based on the abstracts as those that were focussed on DR specifically, and that were not too narrowly focussed technically or highly specific (e.g. describing a specific model or control strategy).

VRE integration

The database Science Direct was searched using the term:

('demand response' OR 'demand side management') AND benefits AND (wind OR solar OR PV OR renewable OR intermittent OR variable)

The results were filtered for journals on the topics of energy or electricity, and filtered for the topics of demand side management or demand response.

The database IEEE Xplore was searched with the same term, and the results were not filtered.

Results from these searches were selected based on the abstracts, to exclude any that focussed specifically on islands or microgrids, or that focussed on describing a specific model or control strategy.

Appendix B: Evidence reviewed

Trials and programmes reviewed

Trial/programme name	Location	Programme/ Trial	Dates	No. of participants
ADDC "Powerwise smart metering trial" [89]	Abu Dhabi	trial	2012 - 2013	400 treatment, 200 control
Ameren Illinois "Power Smart Pricing" [40,41,90–94]	Illinois	programme	2007 - present	500 in 2007; 13,739 in 2013
Ameren Missouri "CPP and TOU trial" [95,96]	Missouri	trial	2004 - 2005	250 treatment, 488 control
Anaheim "CPR trial" [47]	California	trial	2005	71 treatment, 51 control
Australia "Integral energy trial" [97]	Australia	trial	2006 - 2008	900 treatment, 360 control
Austria "Smartgrids Salzburg" [98]	Austria	trial	NK	10 buildings
BC Hydro "TOU/CPP pilot study" [54]	British Columbia	trial	2007 - 2008	1,717
BGE "Smart Energy Pricing Pilot" [99]	Maryland	trial and programme	2008	1,021 treatment, 354 control
CAISO "Flex Alerts" [4,100]	California	programme	2007? To present	Statewide information campaign
California "ADRS" (Automated Demand Response System pilot) [38]	California	trial	2004 - 2005	122 treatment, 104 control in 2004, 98 treatment, 101 control in 2005
California "SPP" (Statewide Pricing Pilot) [101]	California	trial	2003 - 2004	1,759
Cambridge "DLC vs IHD" trial [102]	UK	trial	NK	14
CL&P "Plan-it wise pilot" [19]	Conneticut	trial	2009	1,251 treatment, 200 control
ComEd "CAP" (Customer Applications Pilot) [49,103]	Illinois	trial	2010	8,000
ComEd "Energy smart pricing plan" [26]	Illinois	trial	2003 - 2006	693

Trial/programme name	Location	Programme/ Trial	Dates	No. of participants
ComEd "RRTP" (Residential Real Time Pricing) [104]	Illinois	programme	2007 - present	over 10,000 in 2010 (up from ~500 in 2007). For analysis: 8151 treatment, 872 control
ConEd "CoolNYC" [22]	New York	programme	2012 - present	3,619 devices installed in 2012
Con Ed "DLC trial" [105]	New York	trial	2002	1,752
ConEd "DLC programme" [22]	New York	programme	2002 - present	expects 23,056 devices by end of 2012
Denmark "DR by Domestic Customers using Direct Electric Heating " [27]	Denmark	trial	2003 - 2005	25
DTE "smartcurrents" [17]	Detroit	trial	2012 - 2013	1,915
Duke Energy "Power Manager" [106]	Ohio&Kentucky	programme	'mid-90's' - present	42,597 in Ohio, 9,086 in Kentucky in 2012
Duquesne "Watt Choices" [59]	Pennsylvania	trial	2012 - 2013	1,474
EDF "Millener" [81]	Reunion	trial	NK	over 100 interviews
EDF "Tempo" [18]	France	programme	pilot 1989 - 1992; programme - present	800 in pilot. More than 300,000 in 2004
Energy Australia "Strategic pricing Study" [43]	Australia	trial	2006	650
Energy demand shifting in residential households: the interdependence between social practices and technology design [107]	UK	trial	NK	19
First Energy "consumer behavior study" [20]	Ohio	trial	summer 2012, ongoing	533
Florida Gulf "RSVP/GoodCents Select" [108]	Florida	programme	2000 - present	2,300 by end of 2001

Trial/programme name	Location	Programme/ Trial	Dates	No. of participants
Germany "eTelligence" [109]	Germany	trial	2008 - 2012	650
GPU trial [43]	New Jersey	trial	1997	NK
Green Mountain Power "eEnergy Vermont" [110]	Vermont	trial	2012 (ongoing)	2,565
Hydro One "TOU trial" [111]	Toronto	trial	2007	250
Idaho "Time of day" [112]	Idaho	trial	2005 - 2007	85 treatment in 2006
Intelliekon [113]	Germany, Austria	trial	2008 - 2011	1,114 treatment, 977 control
Ireland "CBT" (Customer Behaviour Trials) [55]	Ireland	trial	2010	4,375 treatment, 1,000 control
Laredo "Customer Choice and Control trial" [31]	Texas	trial	1994 - 1997	650 treatment, 325 control
LIPAedge “DLC trial”[114]	New York	trial	2001 - at least 2005	20,400 on programme. Performance monitored for 400 units
Marblehead Municipal "energysense" [28]	Massachusets	trial	2011 - 2012	500
Mercury Energy "TOU trial" [56]	New Zealand	trial	2008 - 2009	400 treatment, 55 control
Metropolitan Edison (Met Ed) "residential demand reduction programme" [115]	Pennsylvania	trial	2012 - 2013	17,154
Netherlands "powermatching city" [3,116]	Netherlands	trial	2007 - 2014	40 (25 in phase 1)
Netherlands 'Your Energy Moment' [34]	Netherlands	trial	2012 - 2014	251
Newmarket Hydro “TOU pricing pilot” [45]	Ontario	trial	2006 - 2007	220 in analysis
Northern Ireland "Powershift" [117]	Northern Ireland	trial	2003 - 2004	100 treatment, 100 control
Norway "EFFLOCOM trial" (end user flexibility by efficient use of IT) [18]	Norway	trial	2003 - 2004	10,895

Trial/programme name	Location	Programme/ Trial	Dates	No. of participants
Norway “MBDR project” [118]	Norway	trial	2007	40
OG&E "Positive Energy Together" [119]	Oklahoma	trial	2010	3,000
OG&E "Smart Study TOGETHER" [36]	Oklahoma	trial	2010 - 2011	3,000 yr 1, 6,000 yr 2
Olympic Peninsula "Gridwise testbed" [120,121]	Washington	trial	2006 - 2007	116
Ontario "peaksaver programme" [122–126]	Ontario	programme	data 2009 - 2012	~180,000 DLC devices, nearly all on residential AC units
Ontario "smart price pilot" [42]	Ontario	trial	2006 - 2007	373 treatment
Ontario "TOU regulated price plan" [44]	Ontario	programme	2005 - present	over 90% of Ontario
PECO "smart AC saver" [127–129]	Pennsylvania	trial	2012 - 2014	78,651
Penelec "Residential demand reduction programme" [130]	Pennsylvania	trial	2012 - 2013	10,906
Penn Power "Residential demand reduction programme" [131]	Pennsylvania	trial	2012 - 2013	2,661
PG&E "DR contingency reserves trial" [16,24]	California	trial	2009	2,000
PG&E "smart AC" [39,132–136]	California	programme	2007 - present	over 10,000 by end of 2007 - vast majority residential
PG&E "smart rate" [37,124,134,137,138]	California	programme	2008 - present	>10,000 in 2008
PG&E "TOU programme" [37,134,137,138]	California	programme	2008 - present	2008: ~10,000 end of 2012: 78,000
PowerCents DC trial [46]	Washington	trial	2008 - 2009	857 treatment, 388 control
PPL "peaksaver programme" [139]	Pennsylvania	trial	2012 - 2013	43,637

Trial/programme name	Location	Programme/ Trial	Dates	No. of participants
PSE "TOU trial" [43]	Washington	trial	2001 - 2002	~300,000 placed on programme, NK how many opted out.
PSE&G "Mypower Pricing" [140]	New Jersey	trial	2006 - 2007	539 Educate only, 424 automation technology, 450 control
Sala Heby Energi Elnait AB [141,142]	Sweden	trial	2006 - 2012	159, but analysis of 95 due to technical issues
SCE "DR contingency reserves demonstration" [16]	California	demonstration	2008	nearly 800 in phase 2
SCE "DR contingency reserves trial" [16]	California	trial	2009 - 2010	3,255 AC units (residential and small commercial)
SCE "Save Power Days" [52,60,143]	California	programme	2012 - present	~600,000 default 205, 890 opt-in, in 2013
SCE "Summer Discount Plan" [16,60,143]	California	programme	25 + years, ongoing	322,000 in 2008
SDG&E "reduce your use" [48,144]	California	programme	2011 - present	2,907 treatment, 2240 control
SDG&E "smart thermostat pilot" [84]	California	trial	2002 - 2005	3,936 units in 2005
SDG&E "Summer Saver" [145–148]	California	programme	2009 - present	23,602 residential in 2013
SMUD "Residential summer solutions" [21,149]	California	trial	2011 - 2012	265 in 2011, 313 in 2012
SMUD '"SmartPricing Options" [35]	California	trial	2012 - 2013	8,609
Spain "ADDRESS project" [82]	Spain	trial	NK	NK
SVE "empower" [53]	South Dakota & Minnesota	trial	2011 - 2012	<600
Trento Province "TOU regulated price" [150,151]	Italy	programme	2010 - 2011	1,446 in analysis
UK "CLNR" (Customer lead network revolution)" [25,83,152,153]	UK	trial	2012 -2014	628 TOU, 128 smart wet goods, 34 heat pumps

Trial/programme name	Location	Programme/ Trial	Dates	No. of participants
UK "EDRP" (Energy Demand Research Project) [154]	UK	trial	2007 - 2010	SSE: 1,352 treatment (TOU, possibly with other incentives) EdF: 194 treatment (TOU)
UK "Low carbon London" [155,156]	UK	trial	2013	1,119 treatment, 4381 control
UK “Northern Isles New Energy Solutions” (NINES) [157]	UK	trial	2010 - 2012	6 homes
West Penn Power "Energy Savers Reward Programme" [158]	Pennsylvania	trial	2012 - 2013	23573
Xcel "energy pilot" [43]	Colorado	trial	2006 - 2007	2,349 treatment, 1,350 control

Table B1 Trials and programmes reviewed

Surveys, interviews and focus groups reviewed

Study name	Location	Study type	Date	Number of participants
2010 EPRG Public Opinion Survey: Policy Preferences and Energy Saving Measures [159]	UK	Online survey	2010	2,038
2013 EPRG Public Opinion Survey: Smart Energy – Attitudes and Behaviours [160]	UK	Online survey	2013	1526
Consumer acceptance of smart appliances [76]	UK, Italy, Germany, Austria, Slovenia	Surveys and focus groups	Not stated	2907 (surveys only)
Consumer Experiences of Time of Use Tariffs [29]	UK	Interviews	2012	5,914
Dynamic electricity pricing—Which programs do consumers prefer? [161]	Germany	Online survey	Not stated	160
Introducing a demand-based electricity distribution tariff in the residential sector: Demand response and customer perception [141]	Sweden	Interviews	Not stated	10 families, 19 family members
Smart Grid Consumer Survey – Navigant Consulting [162]	US	Online survey	2013	1,084
Smart grids, smart users? The role of the user in demand side management [163]	UK	Focus groups	Not stated	72
Social barriers to the adoption of smart homes [164]	UK	Focus groups	Not stated	~60
The development of smart homes market in the UK [165]	UK	Focus groups	Not stated	~60 (the same focus groups as the paper above)
Transforming the UK energy system – public values, attitudes and acceptability – synthesis report. UKERC. [166]	UK	Survey and focus groups	Not stated	2441 (survey only)

Table B2 Surveys, interviews and focus groups reviewed

Appendix C: Results of studies only reporting response in metrics other than % change in power or energy

All studies of time-of-use/critical peak pricing, critical peak pricing, or critical peak rebate reported results using the metrics of % change in power or energy and so these types of demand response are not represented in this appendix.

Study names are as per Appendix B. See Appendix B for full list of references.

DR type	Study name	Response reported
TOU	Trento Province "TOU regulated price"	Peak shifting clear in morning, new peak created in middle of day, but evening peak shifted forwards and became higher than before.
RTP	ComEd "RRTP" (Residential Real-time Pricing)	"RT-10 alerts generate small hourly savings on the order of 0.0 to 0.08 kW per hour in the mid afternoon to early evening hours, but there is no good statistical evidence that alerts called outside these hours generate savings." RT-10 households also exhibit load shifting on non-event days, which RT-14 customers do not.
	ComEd "Energy smart pricing plan"	50 – 80 W lower consumption per customer on average during higher price hours (mid-afternoon). 5 – 14% additional reduction in daytime during high price alerts.
	Ameren Illinois "Power Smart Pricing"	-4.3% own price elasticity overall. Summer: average reduction of 0.15kW per customer from noon – 5pm, and 0.23kW per customer from noon – 5pm on high price alert days.
dTOU	UK "Low Carbon London"	On average, 0.05kW per household - both reduction for high price periods and increase during low price periods. Decrease in demand was higher during winter, but increase in demand was little affected by time of year.
DLC	PG&E "DR contingency reserves trial"	Up to 84%. Differences attributed to differences in AC use and communication signal strength.
	SCE "DR contingency reserves trial"	Not stated
	SCE "DR contingency reserves demonstration"	Not stated
	SDG&E "smart thermostat pilot"	0.02kW – 0.49kW per AC unit; average 0.3kW.
	ConEd "DLC trial"	1.1kW per AC unit on average
	Laredo "Customer Choice and Control trial"	1.95kW per AC unit on average
	LIPAedge "DLC trial"	15,852 MW – 16,273 MW on aggregate

DR type	Study name	Response reported
DLC	Duquesne "Watt Choices"	0.465MW on aggregate
	Metropolitan Edison (Met Ed) "residential demand reduction programme"	7.45 MW on aggregate
	Penelec "Residential demand reduction programme"	5.35MW on aggregate
	Penn Power "Residential demand reduction programme"	0.93MW on aggregate
	West Penn Power "Energy Savers Reward Programme"	5.86MW on aggregate
	PECO "smart AC saver"	51.3 MW reduction in phase 1; 71.1MW reduction in phase 2, on aggregate
	PPL "peaksaver programme"	16.83 MW on aggregate
	CAISO "Flex Alerts"	2008 - 222 - 282 MW based on self-reported behaviours. 2013 - not statistically significant (issue of coincidence with DR of PG&E)
	Duke Energy "Power Manager"	36 – 49 MW in Ohio; 8.7 – 12 MW in Kentucky (2012 results)
	ConEd "DLC programme"	1 – 1.4kW per AC on average (2012)
	Denmark "DR by Domestic Customers using Direct Electric Heating"	5.3 -2.5 kW per house (depending on temperature – of between -8 to +11 degrees C average daytime temperature).
	UK "CLNR"	2.5kW from DLC of heat pumps
	Norway "MBDR project"	1kWh/h for customers with standard electric water heaters; 2.5kWh/h for customers with electric space heating.

Table C1 Results of studies only reporting response in metrics other than % change in power or energy

Appendix D: Persistence

Studies were considered to offer evidence on persistence of they included text that described enrolment and/or response over time, and/or presented results for enrolment and/or response for two or more years using the same reporting metrics.

The most common metric for response used by these studies was average change in power demand. Percentage changes in response were calculated for studies reporting response using this metric. For both response and enrolment, percentage changes express the change in response or enrolment over the given number of years, as a percentage of response or enrolment levels in the baseline year. Percentage changes are reported across the total period reported, and if greater, the largest change between consecutive years is recorded in the 'notes' column. Where studies reported response as a % rather than an average change in power demand, the % responses across different years were included in the 'notes' section.

Enrolment and response have been judged as stable if they changed by 10% or less across the reported, or were described in a way that indicated they were stable in the study text.

Study names are as per Appendix B. See Appendix B for full list of references.

DR type	Trial Name	reporting period	Increase/ decrease/ stable	% change	notes
TOU	Sala Heby Energii Elnait AB - RECRUITMENT	2005 – 2012	NK	NK	-
	Sala Heby Energii Elnait AB - RESPONSE	2005 – 2012	stable	NK	"six years after the implementation households still respond to the price signals of the tariff by cutting demand in peak hours and shifting electricity consumption from peak to off-peak hours." (pg. 55, [142]).
	UK "EDRP" (EDF TOUT) - RECRUITMENT	2009 – 2010	NK	NK	-
	UK "EDRP" (EDF TOUT) – RESPONSE	2009 – 2010	decrease	NK	"any initial effect is eroded over the first few quarters" (pg. 44, [154]).
	PSE&G "MyPower Pricing" (TOU) – RECRUITMENT	2006 – 2007	NK	NK	-
	PSE&G "MyPower Pricing" (TOU) – RESPONSE	2006 – 2007	stable	NK	"participants consistently lowered their on-peak demand in response to price signals across two summers. During the summer there were daily reductions in demand from 1:00 p.m. to 6:00 p.m. on weekdays due to the on-peak prices in the TOU rate" (pg. 20, [140]).

DR type	Trial Name	reporting period	Increase/ decrease/ stable	% change	notes
TOU	SMUD "Smart Pricing Options" (TOU) - RECRUITMENT	2012 - 2013	stable	-9%	Customer attrition for most plans equalled roughly 25% over the course of the two summers, with the majority of this attrition resulting from customers who moved rather than from those who actively dropped out of the pricing plans. Dropout rates ranged from 4%-9% across different trial treatments. [35]
	SMUD "Smart Pricing Options" (TOU) – RESPONSE	2012 - 2013	stable	NK	Across all participants, and all three DR types included in the trial, no changes in response between the two years was statistically significant. Given the high attrition rate due to moving, response persistence was analysed for customers who stayed on the trial across both years. For opt-out TOU pricing with and without IHD offer, and opt-in TOU pricing without IHD offer, responses persisted across the two years. For opt-in TOU pricing with IHD offer, there was a drop from 0.24kW response per customer to 0.2kW per customer [17%], which was statistically significant at the 95% confidence level. [35].
CPP	PSE&G "MyPower Pricing" (CPP) – RECRUITMENT	2006 – 2007	NK	NK	-
	PSE&G "MyPower Pricing" (CPP) – RESPONSE	2006 – 2007	stable	NK	"participants consistently lowered their on-peak demand in response to price signals across two summers. …When critical peak days were called, customers reacted to the CPP rates and created even more demand reduction during the 1:00 p.m. to 6:00 p.m. period " (pg. 20, [140]).
	Ameren Missouri "CPP and TOU trial" - RECRUITMENT	2004 - 2005	NK	NK	-
	Ameren Missouri "CPP and TOU trial" – RESPONSE	2004 - 2005	increase	18%	Responses reported for CPP tariff only
	Ameren Missouri "CPP and TOU trial" – RESPONSE WITH PCT	2004 - 2005	decrease	-34%	Responses reported for CPP tariff only

DR type	Trial Name	reporting period	Increase/ decrease/ stable	% change	notes
CPP	SMUD "Smart Pricing Options" (CPP) - RECRUITMENT	2012 - 2013	stable	-9%	Customer attrition for most plans equalled roughly 25% over the course of the two summers, with the majority of this attrition resulting from customers who moved rather than from those who actively dropped out of the pricing plans. Dropout rates ranged from 4%-9% across different trial treatments. [35]
	SMUD "Smart Pricing Options" (CPP) – RESPONSE	2012 - 2013	stable	NK	Across all participants, and all three DR types included in the trial, no changes in response between the two years was statistically significant. Given the high attrition rate due to moving, response persistence was analysed for customers who stayed on the trial across both years. For opt-out TOU pricing with and without IHD offer, and opt-in TOU pricing without IHD offer, responses persisted across the two years. For opt-in TOU pricing with IHD offer, there was a drop from 0.24kW response per customer to 0.2kW per customer [17%], which was statistically significant at the 95% confidence level. [35].
TOU-CPP	California "SPP" – RECRUITMENT	2003 – 2004	stable	NK	"turnover among treatment customers is almost exactly the same as turnover among control customers, suggesting that relatively few customers dropped off the experiment because of the treatment itself" (pg. 28, [101])
	California "SPP" - RESPONSE	2003 – 2004	stable	NK	"Differences in peak-period reductions across the two summers… were not statistically significant." (pg. 6, [101])
	SMUD "Smart Pricing Options" (TOU-CPP) - RECRUITMENT	2012 - 2013	stable	-9%	Customer attrition for most plans equalled roughly 25% over the course of the two summers, with the majority of this attrition resulting from customers who moved rather than from those who actively dropped out of the pricing plans. Dropout rates ranged from 4%-9% across different trial treatments. [35]
	SMUD "Smart Pricing Options" (TOU-CPP) – RESPONSE	2012 - 2013	stable	NK	Across all participants, and all three DR types included in the trial, no changes in response between the two years was statistically significant. Given the high attrition rate due to moving, response persistence was analysed for customers who stayed on the trial across both years. For opt-out TOU pricing with and without IHD offer, and opt-in TOU pricing without IHD offer, responses persisted across the two years. For opt-in TOU pricing with IHD offer, there was a drop from 0.24kW response per customer to 0.2kW per customer [17%], which was statistically significant at the 95% confidence level. [35].

DR type	Trial Name	reporting period	Increase/ decrease/ stable	% change	notes
TOU-CPP	SMUD "Residential Summer Solutions" (TOU-CPP) – RESPONSE	2011 - 2012	stable	NK	"For all treatments, non-event peak and event peak savings stayed level or improved in the second year" (pg. 39, [149]). (The trial included multiple DR types but did not report recruitment figures for each DR type separately.)
	OG&E "smart study together" (TOU-CPP) - RECRUITMENT	2010 - 2011	increase	105%	The trial involved a second round of recruitment in the second year of the trial
	OG&E "smart study together" (TOU-CPP) – RESPONSE	2010 - 2011	increase	NK	Analysis compares responses by two different consumer groups: those recruited during the first and during the second year of the trial. Authors suggest there "could be an indication that those customers who have more experience with the rate are learning how to respond better", but that "the PCT is not as conducive to learning and improving price responsiveness over time" compared to manual responses enabled by information from IHD or web portal. The description suggesting a learning effect and increased response applies to both types of pricing included in the trial. (pg. 4-11, [36])
VPP	OG&E "smart study together" (VPP) - RECRUITMENT	2010 - 2011	increase	104%	The trial involved a second round of recruitment in the second year of the trial
	OG&E "smart study together" (VPP) – RESPONSE	2010 - 2011	increase	NK	Analysis compares responses by two different consumer groups: those recruited during the first and during the second year of the trial. Authors suggest there "could be an indication that those customers who have more experience with the rate are learning how to respond better", but that "the PCT is not as conducive to learning and improving price responsiveness over time" compared to manual responses enabled by information from IHD or web portal. The description suggesting a learning effect and increased response applies to both types of pricing included in the trial. (pg. 4-11, [36])
DLC	California "ADRS" – RECRUITMENT	2004 – 2005	decrease	-20%	-
	California "ADRS" – RESPONSE	2004 – 2005	decrease	NK	The reported response fell from 51% to 43%. The reduction is mostly attributed to lower control group loads in 2005, even though temperatures were higher in 2005.

DR type	Trial Name	reporting period	Increase/ decrease/ stable	% change	notes
DLC	SMUD "Residential Summer Solutions" (DLC) – RESPONSE	2011 - 2012	stable	NK	"For all treatments, non-event peak and event peak savings stayed level or improved in the second year" (pg. 39, [149]). (The trial included multiple DR types but did not report recruitment figures for each DR type separately.)
Info only	SMUD "Residential Summer Solutions" (info only) – RESPONSE	2011 - 2012	stable	NK	"For all treatments, non-event peak and event peak savings stayed level or improved in the second year" (pg. 39, [149]). (The trial included multiple DR types but did not report recruitment figures for each DR type separately.)
TOU, CPP	Idaho "TOD" – RECRUITMENT	2006 – 2007	stable	-4.60%	The trial included time of use and critical peak pricing but did not report recruitment figures for each DR type separately.
	Idaho "TOD" – RESPONSE	2006 - 2007	NK	NK	-
TOU-CPP, DLC, info only	SMUD "Residential Summer Solutions" – RECRUITMENT	2011 - 2012	stable	-5%	"90% of the 2011 Summer Solutions participants signed up again for Summer Solutions 2012"... "5% of the 2011 participants dropped out of the study". (pg. 14, [21]). The trial included multiple DR types but did not report recruitment figures for each DR type separately. Response figures were reported for each DR type and can be found in the relevant sections of this table.

Table D1 Trials reporting recruitment and/or response over multiple years

DR type	Programme name	reporting period	Increase/ decrease /stable	% change	notes
TOU	PG&E "Time of use tariff" – RECRUITMENT	2009 - 2012	increase	17%	The increase in enrolment reflects recruitment to a new TOU tariff (E6). Older TOU tariff (E7) closed for recruitment across all 4 years. Greatest % change between consecutive years: +24% (2011 - 2012).
TOU	PG&E "Time of use tariff" – RESPONSE	2009 - 2012	stable	0%	Average kW responses identified for study years 2009 and 2012 only. Average % responses varied from 9.6% to 12% over the four years. In 2012 the reported results included participants in a new TOU tariff (E6). Older TOU tariff (E7) was closed for recruitment across all 4 years.
CPP	PG&E "Smart rate" – RECRUITMENT	2008 - 2012	increase	688%	Stopped actively marketing in 2010 due to regulatory uncertainty. Greatest change between consecutive years: +239% (2011 - 2012).
CPP	PG&E "Smart rate" – RESPONSE	2008 - 2012	decrease	-33%	Largest change year-to-year: -23% (2008 - 2009).
CPR	SDG&E "Reduce Your Use" – RECRUITMENT	2012 - 2013	increase	32%	Customers were recruited on an opt-out basis and could opt-in to receive alerts of critical peak periods. This analysis reflects opt-in to alerts rather than total enrolment. 2011 was a pilot year and was excluded from this analysis.
CPR	SDG&E "Reduce Your Use" – RESPONSE	2012 - 2013	stable	9%	Only one event was called in 2013, on a Saturday. The % change was calculated comparing reported response for this event with the average responses for events on Saturdays in 2012. Considering the average of all events in 2012, the change is +33%.
CPR	SCE "Save Power Days" - RECRUITMENT	2012 - 2013	NK	NK	Customers were recruited on an opt-out basis and could opt-in to receive alerts. Opt-in to alerts was reported for 2013 only.
CPR	SCE "Save Power Days" – RESPONSE	2012 - 2013	stable	NK	"Opt-in and default PTR percent impacts were similar to the 2012 impacts" [52].
VPP	EDF "Tempo" - RECRUITMENT	NK	NK	NK	-
VPP	EDF "Tempo" – RESPONSE	NK	stable	NK	"consumption reduction is more or less stable over the years"

DR type	Programme name	reporting period	Increase/ Decrease/ stable	% change	notes
DLC	PG&E "Smart AC" – RECRUITMENT	2007 - 2012	increase	1390%	Greatest change in consecutive years: +690% (2007 - 2008).
	PG&E "Smart AC" – RESPONSE	2007 - 2012	decrease	-54%	Greatest change in consecutive years: +127% (2010 - 2011; suggests increase likely due to changes in control strategy).
	SDG&E "Summer Saver" – RECRUITMENT	2009 - 2013	stable	-4%	Greatest change in consecutive years: -6% (2011 - 2012).
	SDG&E "Summer Saver" – RESPONSE	2010 - 2013	increase	20%	Only ex-ante results identified for 2009. Greatest change in consecutive years: +27% (2011 - 2012).
	SCE "Summer Discount Plan" – RECRUITMENT	2010 - 2012	decrease	-12%	Reported as number of accounts called during events rather than number of consumers enrolled. Number of accounts called not identified for 2011.
	SCE "Summer Discount Plan" – RESPONSE	2010 - 2012	decrease	-64%	Began to operate as price responsive rather than emergency programme in 2012. Level of response not identified for 2011.
	Ontario "Peaksaver" – RECRUITMENT	2009 - 2012	increase	28%	Reported as number of control devices rather than number of participants. Suggests not all devices are notified to central reporting so true numbers may be higher. Greatest change in consecutive years: +36% (2009 - 2010).
	Ontario "Peaksaver" – RESPONSE	2010 - 2012	stable	-6%	2009 events were carried out purely to test measurement and verification procedures, so were excluded from this analysis. In 2010 and 2012 a proportion of events were called to test measurement and verification procedures, and these were excluded from this analysis. In 2012, the methodology was changed to include comparison with control groups. Greatest change in consecutive years: +51% (2010 - 2011).
RTP	Ameren Illinois "Power Smart Pricing" – RECRUITMENT	2007 - 2013	increase	2648%	Not actively marketed in 2007 due to regulatory uncertainty. Relatively little marketing in 2011 and 2012 due to regulatory uncertainty: 5% and 8% recruitment in these years. 12% recruitment in 2013 after active marketing resumed.
	Ameren Illinois "Power Smart Pricing" – RESPONSE	2008 - 2010	stable	0%	Level of response identified for 2008 - 2010 only. Over this period the response was constant, but average response fell by 13% in 2009 and rose again in 2010.

Table D2 Programmes reporting recruitment and/or response over multiple years

Appendix E: The impact of enabling technologies on response

Study names are as per Appendix B. See Appendix B for full list of references.

		Reported response levels (%)				Change in response with enabling technology (%)		
	Study name (further details in parentheses where applicable)	No enabling technology	information	automation	Information + automation	information	automation	Information + automation
sTOU	CL&P "Plan-it wise pilot"	3.10		3.10			0.00	
	Hydro One "TOU trial"	3.70	5.50			1.80		
	Newmarket Hydro "TOU pricing pilot"	4.70		0.00			-4.70	
	Ireland "CBT"	8.80	11.30			2.50		
TOU-CPP - day to day	DTE "smartcurrents" (cool weather)	0.00	0.00	9.07	10.57	0	9	11
	DTE "smartcurrents" (hot weather)	0.00	0.00	26.02	24.94	0	26	25
	BGE "Smart Energy Pricing Pilot"	1.76	4.38			3		
	PSE&G "Mypower Pricing" (hot summer days, with AC)	3.00		21.00			18.00	
	Xcel "Energy pilot" (with AC)	8.21		10.29			2.08	
	OG&E "Smart Study TOGETHER"	10.03	16.84	29.37	25.73	6.81	19.34	15.70
CPP	PowerCents DC trial	13.00		24.00			11.00	
	Green Mountain Power "eEnergy Vermont"	14.30	11.10			-3.20		
	CL&P "Plan-it wise pilot"	16.10		23.30			7.20	
	SMUD "SmartPricing Options" (opt in)	20.90	25.10			4.20		
	Xcel "Energy pilot" (with AC)	38.42		44.81			6.39	
TOU-CPP - critical events	BC Hydro trial	9.20		30.70			21.50	
	DTE "smartcurrents"	12.60	17.45	44.51	43.02	4.85	31.91	30.42
	Mypower Pricing (PSE&G) (with AC)	17.00		47.00			30.00	
	OG&E "Smart Study TOGETHER"	19.80	25.58	38.80	30.60	5.78	19.00	10.80
	BGE "Smart Energy Pricing Pilot"	21.00	27.00			6.00		
	Xcel "Energy pilot" (with AC)	28.75		54.22			25.47	
	Australia "Integral energy trial"	37.00	41.00			4.00		
CPR	Green Mountain Power "eEnergy Vermont"	5.40	5.70			0.30		
	CL&P "Plan-it wise pilot"	10.90		17.80			6.90	
	BGE "Smart Energy Pricing Pilot"	20.94	26.83	32.95		5.89	12.01	-20.94
	First Energy "Consumer Behavior Study"		11.00	8.00				
VPP	OG&E "Smart Study TOGETHER"	11.72	10.99	35.94	28.29	-0.73	24.22	16.57
	OG&E "Smart Study TOGETHER" (critical peak event)	14.52	13.40	32.15	30.78	-1.12	17.63	16.26
	OG&E "Positive Energy Together" (IHD)		11.00	33.00	28.00			
	Average change in response with enabling technology:					**2.5%**	**14.9%**	**13%**

Table E1 The impact of enabling technologies on response

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